THE STREAMING PHENOMENON

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INTRODUCTION

It is the purpose of this paper to supplement an article published in the *Journal*, in January, 1908,[1] (1) by publication of sketches of the streaming phenomenon, omitted from that article, and (2) by an inquiry whether this phenomenon bears any relation to the various subjective visual phenomena described by earlier investigators.

It will be remembered that the streaming phenomenon was first seen by the writer while observing the fluctuation of the negative after-image. It was confirmed at that time by a number of observers, both trained and untrained, and many have since been added to the list. A brief description is brought forward from the previous article.

"When one sits with lightly closed lids, which must be kept from quivering, before a bright diffuse light such as that of a partly clouded sky, and looks deep into the field of vision thus presented, beyond the background as usually observed, one sees about the point of regard, after the field of vision has steadied, slowly moving swirls. These swirls have the appearance of streams of granules moving in broad curves now this way, now that, seemingly without order, unless a noticeable eye-movement occurs, or is made voluntarily, when the direction of streaming changes to that of the eye-movement. The change of direction is always on a curve, the abruptness of which depends upon the vigor of the movements, much as would happen if motions of different directions and of different magnitude were compounded upon a fluid of considerable inertia. The phenomenon is extremely varied. Sometimes the central portion of the field of vision resembles the surface of a liquid about to boil, channeled this way and that by convection-currents moving at varying rates of speed. Now and again a heavy stream will sweep across this channeled surface from one direction or another, taking up the minor swirls as sharply curving tributaries, and so on, through manifold changes. Various patterns can be picked out, and a particular swirl may be traced in its devia-

[1] C. E. Ferree: *The Intermittence of Minimal Visual Sensations*, XIX, 58 ff.

tions for a time; but, as a whole, the phenomenon cannot be adequately described."

"After practice on the closed lids, the observers became able to trace the streaming on any dull or rough surface with the eyes open." Many were able to see it in this way even before they were able to distinguish it on the field of the closed lids. It "comes out with remarkable clearness with open eyes in the blackness of the dark room. The field of slightly luminous haze that there confronts one . . . . . streams and whirls with convincing distinctness."

"It may also be observed under the conditions of observation of the entoptic and circulation phenomena; but just as one must look beyond the false scotomata to see the moving corpuscles and interspaces, so must one look beyond them to see the streaming."

Other conclusions must be briefly called to mind from the previous article. (1) Streaming cannot be an entoptic, circulation, or tear film phenomenon or any of the shadow phenomena, since it is seen in the darkness as well as in the light, and is, besides, radically different in behavior from these phenomena. (2) The direction and vigor of streaming are to a high degree dependent upon the direction and vigor of eye-movement. (3) Streaming has a characteristic effect upon the visual processes. For (*a*) the streams carry with them the visual quality of the background from which they come. (*b*) They tend to obliterate the negative after-image, *i. e.*, gentle streaming dims the after-image and stronger streaming blots it out. Streaming also conditions every color change in the flight of colors. And (*c*), since the negative after-image represents the obverse or recovery phase of the visual processes, streaming brings about the recovery of the adapted retina,—roughly, at least, to the extent to which it increases the fluctuation and decreases the duration of the negative after-image. (4) The streaming material can quite conceivably be identified with the metabolic substance as the vehicle of both the anabolic and catabolic processes. Metabolism requires the diffusion of lymph over the retina. The streaming of this lymph hither and thither brings to the adapted area anabolic material and carries from it catabolic waste. This catabolic waste is probably in part disintegrated visual substance, which retains for a time its power to condition visual sensation (as is shown by the fact that the streams carry with them the visual quality of the region from which they come). Thus, heavy streaming, by weakening the negative process through hastening anabolic change, and by setting up strongly the sensation of the region from which the streams come, may temporarily obscure the after-image. The effect upon the duration of the after-image is probably to be explained wholly in terms of the facilitation of the anabolic process.

Sketches of the Stream Patterns.

The sketches shown in the following cuts were selected at random from a number drawn by the observers. In cuts 1-10 are given illustrations of a few of the more noticeable and easily represented patterns for two observers, Dr. Bair and Miss Alden. In cuts 13-29 are shown the streams that caused the fluctuation in two observations on the connection between streaming and fluctuation. Figures 11-12 represent two stream-types, some form or modification of which was reported by all of the observers.

It will be understood that these sketches do not represent the phenomenon *in toto*, even for these selected cases. They are but a few patterns dissected out, as it were, from the complexity of streaming. It would be impossible to portray even a single cross section of the disturbance, unless the visual field could be fixed for that instant.

Figures 1-6 were drawn by Dr. Bair (*B*). The observation was made near the middle of a clear day in Colorado, October, 1907. The observer sat about three m. from a long window facing the south, and obtained the after-image of a strip of Milton-Bradley yellow paper, 42 by 4 cm., pasted upon a sheet of Milton-Bradley blue, 50 by 60 cm. On the field of the closed lids this stimulus gave a violet strip on a reddish yellow field, a condition especially favorable for the observation of streaming and its effect on the visual processes. This series of sketches is not continuous, representing the fluctuations of one after-image, but is sampled from the observation of several after-images. A break in the outline of the strip in the drawings represents the disappearance of that part of the after-image.

Figure 1 represents a stream which swept to the right and downwards across the after-image, and, turning upon itself sharply in an uncompleted loop, swept back to the left and upwards, blotting out all of the after-image lying between its external borders. In Figure 2 two streams, the one coming from above and the other from below, swept across the after-image from the left in two closely contiguous parabolic curves, blotting out about one-third of the after-image above and below the centre. In all such patterns, when two streams pass near each other, or when a stream turns upon itself, the region between the stream channels is also strongly agitated. This we may call the region of secondary streaming. Figure 3 represents a narrow stream which swept to the right and downwards across the after-image, and, turning, came back upon itself in a broad loop-shaped curve. Two sections of the after-image, each slightly broader than the stream, the one situated above and the other below the centre, were blotted out. In Figure 4 the stream passed across the after-image to the right and, turning broadly upon itself, passed back to the left across the image, and then sharply downwards, losing itself in a broad fan-shaped expansion. Two sections were blotted out; the one short and near the top, the other longer and very irregular in outline,

near the bottom. In figure 5 two streams from the left, the one passing to the right and upward, crossed each other in an X-shaped pattern slightly above the centre of the after-image, blotting out about one-third of its upper half. Figure 6 represents a stream which passed across the image upwards and to the right and, turning upon itself in a vertical oval, passed downward and to the left, along a path nearly parallel to its previous course, cutting out an elongated diamond-shaped section comprising about half the area of the after-image.

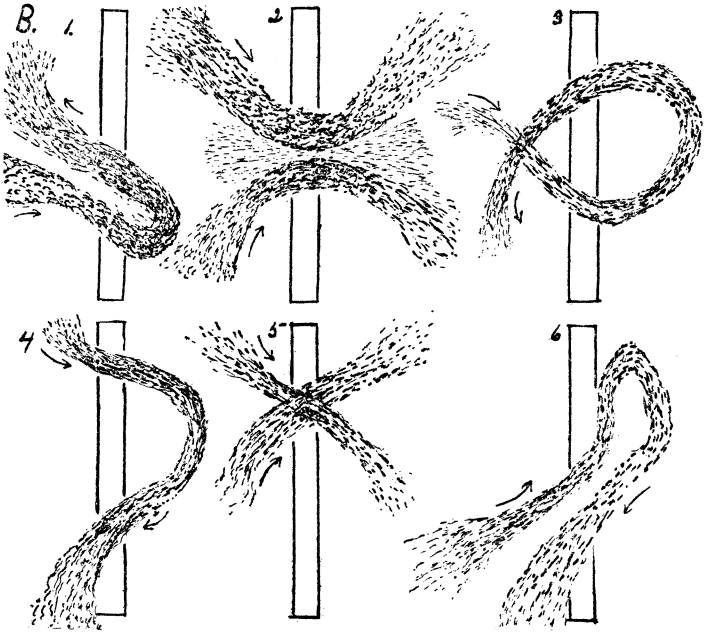

PLATE I

Showing some of the more noticeable and easily represented patterns for Observer *B*. Broken Series.

Figures 7-10 were drawn by Miss Alden (*A*). The conditions for observing 7, 8, and 10 were the same as for the previous observer; but to get the stimulus for Figure 9, the curtain was lowered over the window in front of which the observer sat, and an opening in the shape of a right triangle was cut in it. The sash was lowered and the observer looked through the opening in the curtain at the clear sky. Thus the stimulus was a very bright blue triangle on a dark background.

In Figure 7, first, a stream coming from below and to the left passed across the image, diagonally upwards and to the right. This

was followed immediately by a stream coming from above and to the left which passed diagonally downward and to the right, crossing the path of the first stream in the centre of the field of vision. Before this stream had completed its course, however, it was swept across and taken up by a third stream, moving on a parabolic curve from the right. A large section was blotted out of the central portion of the after-image. In Figure 8, the after-image was swept across, first, by a stream passing downwards and slightly to the right. This was immediately followed by a stream passing upward and slightly to the right. The two streams seemed to form the limbs of a loop, the apex of which was too far advanced into indirect vision to be perceived. Strong secondary streaming was observed to the right of the intersection of the two streams. A large section was blotted out of the centre of the after-image, extending also down the lower left edge. Figure 9 represents a pattern very similar to that of Figure 8, but drafted on broader lines. A wide stream, curving downward and slightly to the right, passed across the triangular after-image, immediately followed by a return stream moving on a similar curve upwards and slightly to the right. This figure also strongly suggested that the two streams were in reality but successive stages of one stream moving in a broad loop-shaped curve. The whole triangle was blotted out,

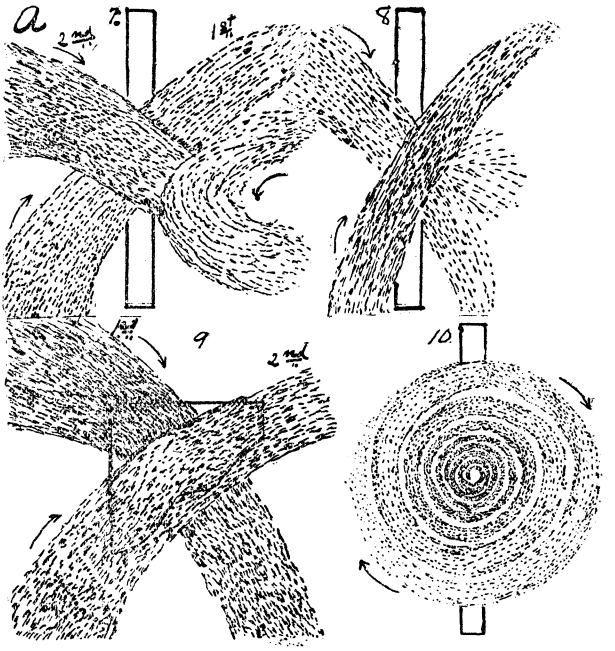

PLATE II

Showing some of the more noticeable and easily represented patterns for Observer *A*. Broken Series.

with the exception of a very small portion of each of the two legs. Figure 10 represents a pattern frequently observed. A swirl small at first begins at the centre of the field of vision and expands centrifugally. It may take in quite a large area of the field of vision before it is swept in this direction or that into a definite stream-form. Expanding as it swirls, and encroaching more and more upon the after-image, this pattern affords a striking and easily observed example of the connection between streaming and the fluctuation of the negative after-image.

Figures 11 and 12 are represented in Plate III.

Figure 12 shows a peculiar pattern, frequently present in some form or other. The stream begins at the periphery in a fan-shaped expansion and moves in a broad curve towards the centre of the field of vision, where it turns sharply upon itself and forms a spiral swirl. At first the movement is slow, but increases rapidly as the stream narrows. Frequently, during the swirling, the movement will reverse and the spiral unwind, sending off a stream towards the periphery which in turn may curve broadly upon itself and return to the centre, thus forming a second swirl similar to the first, and so on through a

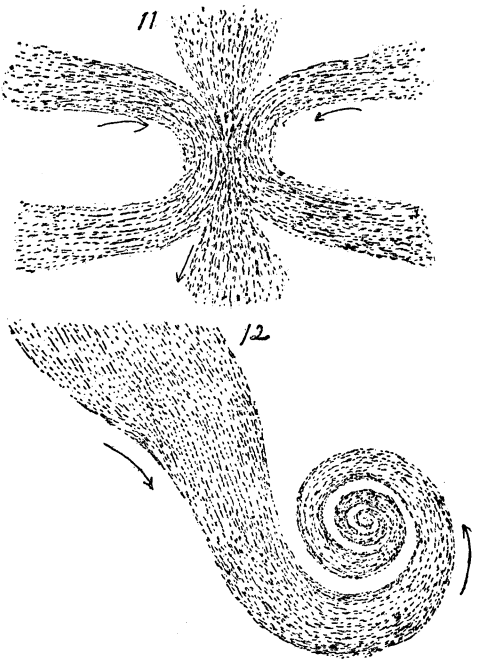

PLATE III

Showing two stream types, some form of which was reported by all of the observers.

number of repetitions. The actual pattern is but inadequately shown in the diagram. Figure 11 shows a very frequent pattern. Two streams moving in opposite directions on a path of slight curvature sweep in towards the centre, and when about to collide turn and complete their paths on parabolic curves. At the apex of each curve the movement is rapid. Strong secondary streaming takes place between the curves, tangent to them at their point of contact, and having the same direction as the primary streaming at this point of contact. In the open this secondary stream is broad and slow, but in the narrow space between the primary streams it is whirled into swift motion. It behaves as if it were drawn in from the surrounding field by the rapid swirl of the primary streams, and were cast out, to lose itself in it again, when the granules of the primary stream enter upon the second part of their course.

Figures 13-21, Plates IV and V, drawn by *A*, represent the streams causing the fluctuation of the after-image of a strip of Milton-Bradley standard yellow paper 42 by 4 cm., from its appearance until its final disappearance. The time of stimulation was 40 seconds, and the distance of the observer from the stimulus was 1 meter. The observation was made in Colorado in October, the observer facing an open window with southern exposure, as was previously described. Only those streams were sketched which caused the after-image to disappear as a whole or in parts.

No streaming was noticeable at first. The after-image was very bright. Gradually a gentle streaming began which dimmed the after-image. Figure 13: a stream moving on a path of slight curvature, downwards and towards the left, swept across the lower part of the after-image. This was immediately followed by a broader stream, of slightly greater curvature, moving downwards and towards the right. The paths of the streams crossed a little to the right of the after-image. The lower third of the image was blotted out. Figure 14: a stream curved downwards and to the left, blotting out about a third of the after-image at the top. Figure 15: a broad, heavy stream, sweeping down from above and to the left, carried the background over the entire image, blotting it out completely. At this point the streaming grew more intensive, the streams became broader and fluctuation became more frequent. Figure 16: a stream sweeping downwards and towards the left blotted out the lower half of the after-image. Figure 17: a broad stream moving almost on the diagonal downwards and towards the left, swept out the whole after-image. Figure 18: a second broad stream, moving downwards and towards the left, but more inclined towards the vertical than the preceding one, passed across the after-image. The streaming was gentle at first, only dimming the after-image, but gaining in intensity soon swept it entirely out. Figure 19: a stream moving towards the right and downwards blotted out the top of the after-image. Before this had passed entirely off the image, a second stream curved downwards and to the left, crossing the first stream to the right of the image, and with it sweeping out the upper two-thirds of the after-image. Figure 20: a broad stream, following the diagonal, swept downwards and to the left across the image, blotting it out completely. Figure 21: a broad stream covering nearly all of the after-image, swept downwards and to the right. Before this had entirely cleared away, a slightly narrower stream came down from

above and the right, crossing the first in an X-shaped pattern. Both streams together blotted out all but the very edge of the bottom and a small portion of the top. From this time on the streaming became still more intensive, and the fluctuation still more frequent. The image would scarcely clear from a previous stream before another swept it out again. The fluctuations were too rapid to fix in mind for sketching. The after-image became dimmer at each reappearance and soon vanished. In all of the above cases the after-image was seen to reappear from behind the stream, as this cleared away, the clearing generally beginning in the direction from which the stream came.

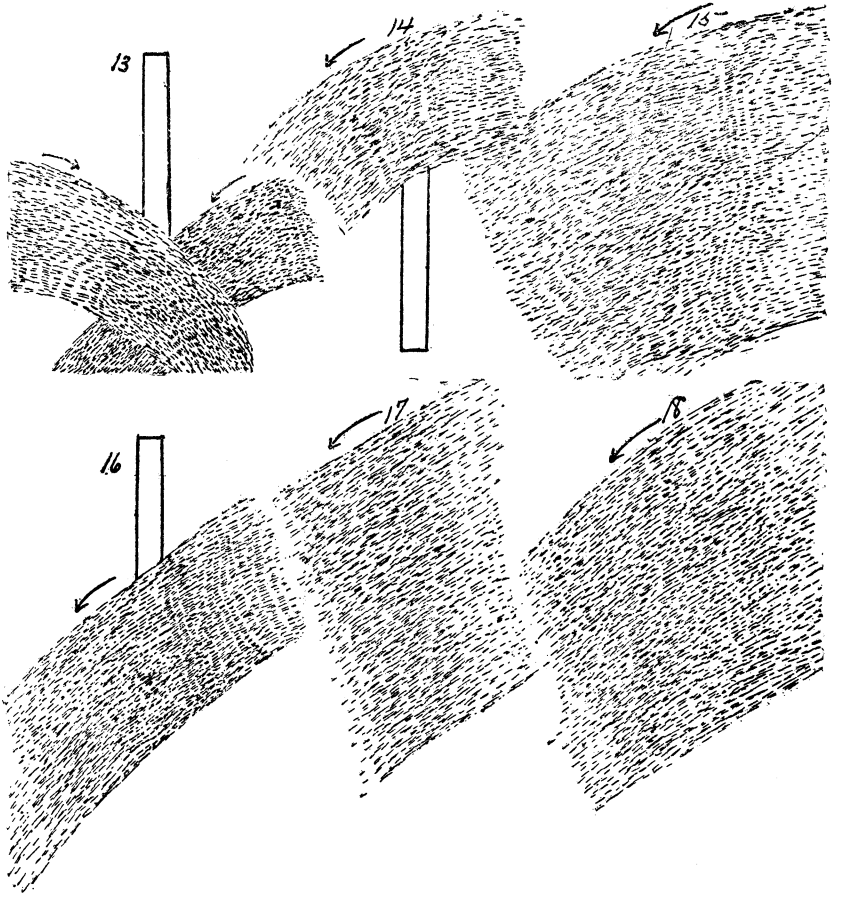

PLATE IV

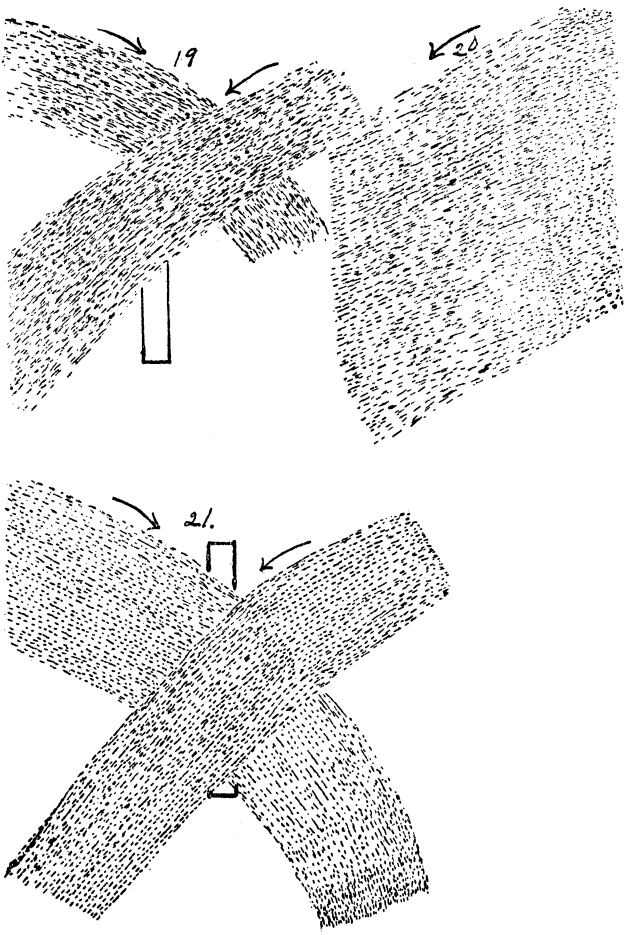

PLATE V

Showing the streams which caused the fluctuation of a given after-image for Observer *A*. Time of stimulation : 40 sec.

Figures 22-29 illustrate still further the connection between streaming and the fluctuation of the negative after-image. The stimulus and experimental conditions were the same in this case as in the former, with the exception that the time of stimulation was only 30 seconds. In a comparison of the two series, a difference will be noticed in the character of the streaming. In the first series the streams were of the nature of

bold, vigorous sweeps of little curvature, such as are caused by eye-movements of considerable range, while in this series they show a more pronounced curvature and are in general more complex in pattern. This difference may be accounted for in part by the difference in the time of stimulation (which permitted the observer a better control of fixation on projection of the after-image), but is probably due largely to the individual difference in steadiness of fixation for the two observers, as shown by their eye-movement records.

There was first a gentle streaming over the whole area of the after-image. A light stream (Figure 22) swept downwards and towards the right, almost, but not entirely, blotting out the after-image. Figure 23: a swirl moving counter-clockwise and coming from above and to the right, was carried across the upper half and centre of the after-image, causing a long disappearance. This is a peculiar and not infrequent form of streaming. Two independent motions are impressed upon the same particles. The granules revolve about a common centre and at the same time are carried forward in a linear path, much as are the atmospheric particles in the vortex of a storm cloud. At times the vortex motion is not so prominent, the phenomenon presenting the appearance of finely powdered snow driven before a brisk wind. Figure 24: two streams, the one moving from the left, the other from the right, joined and passed upwards, blotting out the after-image along its entire length. Figure 25: a stream moving obliquely down and to the left, swept out the lower part of the after-image. Almost immediately another, apparently a continuation of the first, swept up and to the right, carrying out the centre and upper half. Figure 26: a swirl moving counter-clockwise cut off the top of the after-image. Figure 27: a stream moving across the centre from the left, when considerably beyond the after-image, divided and swept back on itself in two broad curves, carrying out the centre, top, and bottom of the image. Figure 28: a stream moving on a very gradual curve to the right, downwards, and to the left, blotted out all but the right edge of the lower half of the after-image. Figure 29: a heavy stream moving across the centre from the right divided and swept back on itself obliquely towards top and bottom, carrying out the whole after-image. From this time on, the visual field was in more or less general commotion. The fluctuation consisted of faint, short appearances, usually of only a part of the after-image at a time, and of long disappearances. The image soon vanished.

The Circulation Phenomenon

In the previous article, the writer showed that the streaming phenomenon cannot be identified with any of the known entoptic or circulatory phenomena of the retina. It devolves upon him here to show that it cannot be identified with any other of the subjective visual phenomena hitherto described, or with any unclassified observations that have been reported in the description of these phenomena or of the circulation phenomenon. To this end it will be necessary to take into account the published accounts of the circulation phenomenon,

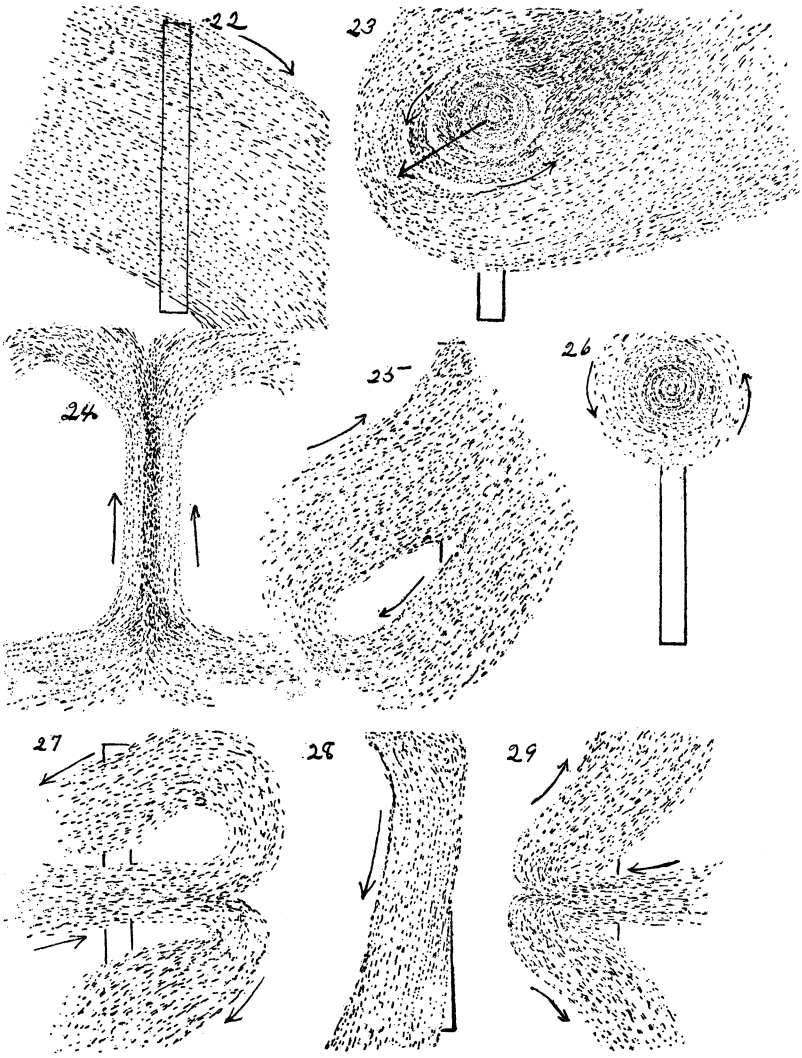

Plate VI

Showing the streams that caused the fluctuation when the after-image was projected with a steadier fixation than obtained for *A* in Plates IV, V.

and of that indefinite group of phenomena called variously *Lichtchaos*, *Lichtstaub*, *wandelnde Nebelstreifen*, etc.

The first reference to the circulation phenomenon appears to have been made by Sauvages.[1] It occurs, however, in his chapter on vertigo, and can scarcely be considered an observation of the normal circulation of the blood. He says: "Si oculis parietem album proximum respicientibus, lucem retro accedentem, solarem non tamen directam sed reflexam recipiat paries, observator videt in muro reticulum obscurum, mox evanescentem."

Darwin, Steinbuch, Purkinje, Ruete, Meissner, Johannes Müller, Vierordt, Rood, Rogers, Aubert, Helmholtz, Odgen and others (see footnote 2, p. 500), have also described the circulation phenomenon; but for our purpose Vierordt's report alone will repay close investigation. The others will be briefly considered merely for the sake of historical continuity.

The first report of the normal flow of the blood through the retinal capillaries was made by Darwin,[2] who states that he could see the moving corpuscles when gazing at the sky or some other bright field, after holding his breath or rubbing his eyes. A few years later Steinbuch,[3] who believed that he was able to distinguish the outline of the vessels as well as the movement of the corpuscles. He found that observation is facilitated by pressure on the eye-ball, when "Reihen von fliessenden Kügelchen" are plainly seen. Purkinje[4] reports that on fixating an extended, well-illuminated surface, bright points are seen in the field of vision, which traverse definite paths at an uniform rate of speed, and appear and disappear at irregular intervals.

Johannes Müller[5] says that a general impression of the movement of the blood may be obtained in many ways; especially if one regards a bright but not shining surface, as the sky, or stares for some time fixedly at the surface of snow or white paper. The phenomenon consists of a confused jumble of intermingling, darting points, or of a vague irregular movement as of mist or smoke, and is so indefinite that not even the direction of movement can be determined.

Ruete,[6] looking at the sky through blue glass, saw many

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[1] Nosol. method., Amsterd., 1763. Tome 3, 242.

[2] R. W. Darwin: New Experiments on the Ocular Spectra of Light and Colors, Philosoph. Transact., LXXVI (2), 1786, 313. See also G. J. Burch, Nature, LIII, 558.

[3] Harless, *Jahrbuch der deutschen Medicin und Chirurgie*, 1813, III., 2, 270.

[4] *Beobachtungen und Versuche zur Physiologie der Sinne I*, 1823, 127.

[5] *Physiologie des Menschen*, 1837, II, 390.

[6] *Bildliche Darstellung der Krankheiten des menschlichen Auges*, 1854, 56.

streams wandering hither and thither, each stream consisting of a single row of alternatingly light and dark points. The points moved in circular paths, convexly curved and frequently intersecting. As pictured by him, the phenomenon presents an appearance very like a hive of bees in the act of swarming. Ruete's description of the circulation phenomenon differs from that given by any other observer ;[1] but it nevertheless no more resembles a description of the streaming phenomenon than do the others. The sole point of resemblance to the ordinary accounts of the circulation phenomenon is the mention of "light and dark points" which are seen "in narrow and unchanging paths of motion." This feature alone, however, would be sufficient to differentiate Ruete's observation either from the streaming phenomenon or from the *Lichtchaos*, *Lichtstaub*, etc. Ruete also mentions that the phenomenon is emphasized by the retinal congestion produced as one suddenly rises from a stooping position.

G. Meissner[2] describes two methods by means of which he was able to observe the retinal circulation. When he looked through a small opening at the bright surface presented by the globe of a lamp, with the eye accommodated for a very short distance, the field of vision suddenly darkened and light flecks of irregular form appeared in great numbers. These flecks were very close together, but distinct in outline from the beginning. Motion was gradually set up among them in the most diverse directions, along paths in some places wide, in others narrow, here separating and there reuniting, with the appearance of vessels in which blood corpuscles were rapidly coursing. In the second method, the one eye was closed and the other looked through a lens at the globe of a lamp placed at such a distance as not to give an image, but an intensely bright, uniformly illuminated field. This, when stared at awhile, became dark and slightly tinged with green ("wahrscheinlich in Folge einer Ueberreizung"). In the field of vision thus formed the circulation was plainly visible.

Vierordt[3] distinguishes four stages in the observation of the circulation phenomenon. His method and observation may be described as follows. The left eye was closed and a sheet of milk-glass, uniformly illuminated and placed at a distance of 100-130 mm., was stared at with the right. The fingers, slightly spread apart, were moved rapidly to and fro (120

[1] Vierordt (*Archiv für physiologische Heilkunde*, 1856, 256), commenting upon this, says: "Ich bin nicht im Stande die Gestalten meiner Blutströmchen in der Ruete'schen Figur auch nur im entferntesten wieder zu erkennen."

[2] *Beiträge zur Physiologie des Sehorganes*, 1854, 84.

[3] *Archiv für physiologische Heilkunde*, 1856, 258.

times per minute or thereabouts) as near as possible to the eyes. After the lapse of a few seconds, never more than a minute, a confused general movement was set up on the white milk-glass surface. This soon resolved itself into numerous light points moving indefinitely hither and thither (first stage), and later into a streaming of the points in definite and fixed directions, but not in channels or paths that were themselves distinguishable (second stage). In a short time, on account of fatigue of the retina, the bright white spaces between the streams became darker. The stream paths themselves, becoming slightly darker, were thus rendered plainly visible. A peculiar state of fluctuation was now induced. Sometimes the visual field would become white again, in which case the stream paths became indistinct (second stage). Then the visual field would again become darker, *i. e.*, become a grayish green, whereby the larger vessels would be made apparent in a brownish color and clearly outlined (third stage). The smaller vessels, however, were still unrecognizable, and the observer received only the general impression of movement, without being able to distinguish the individual corpuscles. Between these two extremes lay an intermitting middle state (fourth stage). The long narrow spaces between the vessels became uniformly light, and frequently also the individual corpuscles could be sharply distinguished as faintly yellowish points. Vierordt says that this fourth stage is that best suited to the observation of the phenomenon, which presents a very surprising and striking appearance, often lasting from 2 to 4 minutes. For observation at this stage the finger movements may be slowed, but cannot be dispensed with entirely.

A difference of opinion seems to exist with regard to Vierordt's observation. Vierordt himself considers it an observation of the circulation phenomenon, and discusses it with that reference throughout. Helmholtz,[1] however, discusses it under the heading *Lichtschattenfigur*, and other systematists, doubtless following his lead, also treat it as a phenomenon of intermittent illumination. Helmholtz, who produces his alternation of white and black sensations by staring at a rotating disk made up of white and black sectors, instead of moving the fingers before the eyes, as Vierordt did, describes the phenomenon as a formless streaming, the direction of which may change as it proceeds, and attributes it to a circulation of lymph rather than to the circulation of the blood. It is chiefly on account of this conflict of opinion, and not by reason of any similarity between this and the streaming phenomenon, that Vierordt's observation and the circulation

[1]Physiol. Optik, 1896, 533.

literature in general have been considered here. Vierordt himself is clear that the streaming is not formless and vague. The third stage might possibly be so construed, out of connection with stages 2 and 4, but in habitually changing to these its character is plainly revealed. Nor do the streams ever shift their paths hither and thither. Whatever Helmholtz may have seen, or however it may bear on this problem, Vierordt's observation cannot easily be misconstrued. It is one of the most definite descriptions of distinct and fixed stream-paths to be found in the literature of the circulation phenomenon. The report throughout conveys the impression of retinal capillaries and interspaces and circulating corpuscles, and Vierordt adopts these terms at the very beginning of his discussion as most fittingly characterizing what he saw.

O. N. Rood recommends the use of cobalt glass for the observation of the circulation phenomenon. Describing it, he says:[1] "The moving bodies at first appeared very closely packed together like fine mosaic work, but as the view grew more distinct their paths could be traced, and the conviction was forced on the mind of the observer, that they were moving at slow uniform rates through narrow channels, the whole reminding one strongly of the circulation seen in the web of a frog's foot through a microscope slightly out of focus." The indistinct vision attendant upon faintness or mere eye-weariness, is, he thinks, in many cases, mediately caused by the appearance of this circulation. For example, he tried the experiment of binding up the right eye and using only the left for two days. After reading with the left eye for half an hour, the page grew indistinct, the letters apparently dissolved, and the dense circulation which he had previously observed was set up, and continued to be visible for some minutes. Under these same circumstances it reappeared several times during that and the following day.

W. B. Rogers,[2] observing in co-operation with Rood, was able to get the phenomenon especially well after long or fatiguing work with the eyes, after active exercise, or indeed, after anything that stimulated the circulation. He describes it as follows: "When I look intently with the naked eye upon a bright surface such as that of a white cloud or a sheet of letter paper in the sunlight, the first appearance presented is that of numerous bright points darting around in various broken curves, coming into view and disappearing fitfully, but in such positions as to indicate the recurrence of the same motions, or the passage of successive particles in certain pre-

[1] Silliman's *Amer. Journal of Science*, November, 1860, 385. See also the September number of the same year.

[2] *Ibid.*, 386.

scribed and permanent channels. As the eyes continue to be fixed on the surface, a shade comes over it, and on the dark ground innumerable streams of particles are seen, moving in infinitely various loops and other curves which, by a little attention, are observed to maintain a constant pattern, strikingly analogous to the capillary circulation as seen under the microscope. These streams of particles are of a tawny yellow as contrasted with the dark brownish surface on which they appear." He also gets the phenomenon very well by looking through a black tube at a white surface until the eye has become fatigued, or with the lens of a pocket microscope held at about the focal distance from the eye.

Aubert[1] says that when he presses lightly upon the ball of the eye he can see, with remarkable distinctness, the circulation in the vessels lying close to the yellow spot. The corpuscles move in single file along fixed paths. These paths form very small angles with each other, do not often anastomose, and frequently appear to cross each other without anastomosis. The size of the corpuscles is apparently about fifty times the size of the corpuscles in the capillaries of the frog's foot as seen under the microscope. Pulsations are plainly in evidence but become weaker as the pressure continues.

Describing the circulation as it appears in the visual field of his right eye, Helmholtz[2] reports that it is seen with remarkable clearness in two parallel vessels situated just to the left of the fixation point. The movement is "scheinbar nach oben gerichtet und das bewegte Gebilde verschwindet, indem es sich mit beträchtlich gesteigerter Geschwindigkeit durch eine S-förmige Krummung hindurchwindet." In both of these cases the vessels present a peculiar branched, tree-shaped appearance. The phenomenon often repeats itself, and sometimes in both vessels simultaneously. It occurs also, but less distinctly, at other places in the visual field. Helmholtz explains it as follows. Obstructions are formed here and there by large corpuscles, which dam up the capillaries in their more constricted portions. The corpuscles just in front of these obstructions move on, while those behind crowd against them, thus forming alternating translucent and opaque sections in the capillaries, which are seen as light and dark spaces. These suddenly dart forward or stop, according as the obstruction is overcome or reforms; and so arises the peculiar intermittent, darting movement that characterizes the capillary circulation as seen subjectively, or under the microscope.[3]

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[1] *Physiologie der Netzhaut*, 1865, 342.
[2] *Physiol. Optik*, 198 f.
[3] For other explanation see Rood (*loc. cit.*); Boisser: Landois and Stirling, Manual of Human Physiology, 1895, II, 995; and Ogden's criticism of Helmholtz (*loc. cit.*).

Ogden,[1] working in 1901, in addition to an introspective report, set for his observers the definite task of mapping the course of the blood-vessels. In his report two of these maps are published, showing the paths of both the large and the small streams, also the direction of the movement of the blood streams in them. Describing the phenomenon, his observer *B* distinguishes two classes of movement. In the one, taking place for the most part beyond the macular region, the spots moved rapidly over a considerable distance and scarcely more than indicated their general direction of motion. In the other, near the macula, they moved more slowly over shorter distances and described definite courses. Both corpuscle and path were plainly distinguished. Observations were made also of color and brightness of corpuscle and interspace.[2]

Other Movement Phenomena.

It is, of course, well known that, for the normal eye, the darkened field of vision is not black. It is covered unevenly with shifting, changing clouds of a luminous gray. Purkinje[3] employed the term *Lichtchaos* to cover in a general way this type of phenomenon. A frequent variety, which we shall need to consider here, has been called by Goethe[4] *wandelnde Nebelstreifen*. Purkinje (*loc cit.*) describes it as follows. When one stares into a carefully darkened field of vision, a faint, fantastic image appears and begins to move. At first it is variable and formless, but later it becomes more definite in outline. In general it consists of bands of light and shadow more or less arched, which move

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[1] This *Journal*, XII, 381-391.

[2] Space has not been given to the following reports because they do not add anything of importance to our discussion of those already given.

L. Reuben: On Normal Quasi-vision of theMoving Blood Corpuscles within the Retina of the Human Eye. Sill. Journ. (2), XXXI, 1861, 325-338. *Ibid.*, 417.

B. A. Pope: Entoptische Erscheinungen im Zusammenhang mit dem Blutkreislauf, Arch. f. Augen- u. Ohrenheilkde, I, 1869, 72-78, *Ibid.*, 459.

B. Becker: Ueber die sichtbaren Erscheinungen der Blutbeweg ungen in der menschlischen Netzhaut. Berlin, 1872.

S. E. Ayers: Der Blutlauf in der Gegend des gelben Flecks. Arch. of Opthalm. XI, 1882, 476. Arch. f. Augenheilkde. XIII, 1883, 29.

J. W. Barrett: Nature, LIII, 510.

G. J. Burch: *Ibid.*, 558.

For methods of mapping the retinal circulation see Ayres (*loc. cit.*); Ogden (*loc. cit.*); Randall, in de Schweinitz, Amer. Text-Book of Diseases of the Eye, Ear, Nose and Throat, 1889, 140; and O. W. Maher, Austral. Med. Gaz., IV, 38.

[3] *Beobachtungen und Versuche zur Physiologie der Sinne*, 1823, I, 58.

[4] *Farbenlehre*, Abth. 1, § 96.

"als concentrische Kreise gegen den Mittelpunkt des Sehfelds, und dort sich verlieren, oder als wandelnde Bogen an ihm sich brechen und in sich selbst zusammenkrümmen, oder als krumme Radien um ihn im Kreise sich bewegen." Its movement is slow. Eight seconds are usually required for one of the bands to run its course and disappear. From the beginning of the observation the darkness is never absolute. The field of vision is filled with a boundless chaos of weak light.

Observing more in detail, Purkinje distinguishes four cases of the phenomenon, which are described as follows. (1) A weak light in centripetal motion is seen in the centre of the field of vision. Surrounding this is a black band, which in turn is bounded peripherally by a belt of dull light. These move inward, and seem to displace the central luminous spot as a round dark area. Next the whole pattern (luminous ring, dark band, and faintly luminous, shimmering fringe) re-forms about this dark area, and, moving inward as before, takes its place. See Plate VII, figure 17.

(2) Broad luminous and broad black bands form alternately above the centre and move towards it. As they proceed they bend to form arcs which grow smaller and smaller, uniting into a single light-mass, and finally disappearing at the centre. See figure 18.

(3) Analogous to these are other patterns in which the light and dark bands extend either vertically or obliquely, and move towards each other. See figure 19.

(4) A fourth form consists of two-curved bands which extend from the middle point of the visual field in opposite directions, and turn about it. Later, after the attention has become fatigued, these patterns give place to irregular waves of light and shadow. Finally, these subside and there appears to be drawn over the visual field a scarcely perceptible veil of dull light.

PLATE VII

Showing Purkinje's drawings of the *wandelnde Nebelstreifen*: drawings 17, 18, 19.

Johannes Müller[1] describes the subjective lighting of the visual field somewhat differently. "At times the phenomenon appears as a general illumination of the field of vision. Again it takes the form of a bright shimmer, which spreads out in circular waves towards the periphery and vanishes. Frequently the shimmer is flecked, cloud-like and nebulous. And very rarely the phenomenon repeats itself with a sort of rhythm."

Volkmann[2] says that, when the eyes are closed and covered, the field of vision is seen to be filled irregularly with a sort of *Lichtstaub* which is present in different amounts under different circumstances. (Fechner, for example, after his prolonged investigation of the physiological colors got it in such excessive amounts for a year that he called it "*ein Lichtmeer*".) Color phenomena are also perceived, the colors, varying at different times. An observation made by Volkmann soon after awaking in the morning is reported as follows: "There was at first a shadow-field containing a small amount of light-dust which streamed from left to right. This light-dust increased, and a reddish centre formed in the shadow-field. The reddish centre became quadrangular in shape and spread out gradually over the whole visual field. In the centre of the red field thus formed, a green spot appeared, which likewise expanded, until it covered the visual field. Again a red spot developed at its centre, and spread as before. The red field of vision was thickly dotted or pointed, the points streaming from left to right." Sometimes violet and green were seen instead of red and green, and their order of succession frequently varied.

Aubert[3] describes the subjective light phenomena of the darkened field of vision as follows: (1) The field is never free from points and lines of light which move in a slow peculiar fashion. In appearance the patterns formed can be compared to floating strings of tow. The light mass is yellow in color, is not especially bright, and is variable in amount. (2) Goethe's *wandelnde Nebelstreifen* are often seen floating over the field in various directions. They are indefinite in form, and colorless. Eye-movement or blinking either hastens their movement or causes them to vanish. (3) At times, when the eyes are held especially steady, nebulous balls appear in the middle of the visual field. They alternately expand and contract, but do not move from place to place. They are brightest at the centre and shade off formlessly towards the periphery into the dark background. (4) Very bright points of light appear suddenly and vanish quickly. These points

[1] *Spontane Lichterscheinung im dunkeln Sehfelde:* Physiologie des Menschen, 1837, II, 391.
[2] *Wagner's Handwörterbuch der Physiolgie*, III, 1846, 311.
[3] *Physiologie der Netzhaut*, 1865, 333 f.

are so bright as to be mistaken for objective light. Under the most favorable conditions for observation, they cannot be seen more than a few seconds. (5) And fifthly, zigzag lines are sometimes observed, appearing either as bright, bluish, or violet flashes.[1] They move slowly and vanish after a few seconds. Aubert mentions also rotating shapes resembling comets, colored clouds, and "das eigenthümliche Strahlenschiessen von der Peripherie nach dem Centrum" which Ruete[2] has described. He says that long exposure to dark, so far from interfering with these phenomena, rather serves to intensify them.

Again, Helmholtz[3] reports the *wandelnde Nebelstreifen* as two systems of circular waves which slowly converge from both sides of the visual field towards its middle point. The locus of this middle point, he says, seems to be the entrance of the optic nerve. A certain periodicity obtains which, as it appears to him, roughly coincides with the respiratory rhythm. Lastly, Pierce[4] describes what he calls the "illusory dust drift." When one fixates a set of parallel white and black lines in a strong light for 20 sec. or more, and then transfers the gaze quickly to a square of dull black cardboard, the illusory dust drift may be seen. The appearance is that of a cloud of fine white dust moving across the field of vision in a direction in general perpendicular to the direction of the lines in the stimulus. When the stimulus is an uniform field, instead of lined, the drift does not occur. Pierce explains the phenomenon as an after-image of motion. The parallel lines solicit the eyes to move in a direction perpendicular to them. The numerous involuntary eye-movements thus set up give rise to after-images of motion when the eyes come to comparative rest on the uniform field of the black cardboard.—

It seems clear from this review that the writer was justified in regarding as new his observation of the streaming phenomenon. None of the movement phenomena mentioned agree in any essential particular with the streaming phenomenon. There are disturbances in the field of vision, secondary to streaming and out of the paths of the streams, which may possibly bear some relation to the shifting clouds, etc., of the retinal light; but there is no evidence that the streams themselves, with their definite stream forms, their shifting paths, and, still more distinctive, their characteristic effect on the visual processes, have hitherto been observed.

[1] For a description of the *Zickzacklinien* see also Purkinje, *Beobachtungen*, II, 84.

[2] *Lehrbuch der Ophthalmologie*, 1845, 72, figure 39.

[3] *Physiol. Optik*, 242.

[4] Studies in Space Perception, 331-38.